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DESCRIPTION

ELECTRET AND ELECTRET CONDENSER

TECHNICAL FIELD

[0001] The present invention relates to an electret condenser having a vibrating electrode and a fixed electrode and, more particularly, to an electret condenser formed by using a MEMS (Micro Electro Mechanical Systems) technology.

BACKGROUND ART

[0002] Organic high-molecular polymers such as FEP (Copolymer of Tetrafluoroethylene (TFE) and Hexafluoropropylene (HFP)) materials have been used conventionally for electret elements which are dielectric materials each having a permanent electric polarization and applied to devices such as a condenser microphone. However, since these materials are inferior in thermal resistance, the problem has been encountered that they are difficult to use as elements for reflow when mounted on substrates.

[0003] As a solution to the problem, an electret using a silicon oxide film as shown in Patent Document 1, instead of an organic high-molecular polymer, has been proposed in recent years to provide a thinner-film and smaller-size electret by using a microfabrication technology.

[0004] Specifically, the technology shown in Patent Document 1 deposits a silicon oxide film on a surface of a base, sets a gas atmosphere containing oxygen and containing no moisture in a deposition chamber without releasing the chamber to an ambient atmosphere, performs a thermal process at 200 °C to 400 °C with respect to the silicon oxide film in the atmosphere, and then performs a charging process with respect to the silicon oxide film.

Patent Document 1: Japanese Laid-Open Patent Publication No. 2002-33241

DISCLOSURE OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0005] However, an electret has the problem of losing charge upon contact with a liquid. For example, when electretized FEP is immersed in ethanol, a charge in the FEP is significantly reduced, though the charge does not become zero. According to an experiment conducted by the present inventors, when FEP (specifically, FEP formed on a stainless steel substrate to have a thickness of 12.5 μm) of which the surface potential indicating an amount of charge was 300 V was immersed in ethanol, the surface potential was reduced to the order of several volts. It is to be noted that this phenomenon similarly occurs even when the electret is immersed not only in ethanol but also in another organic solvent or water. In terms of the material also, the phenomenon is not peculiar to FEP but similarly occurs in a general electret material such as a silicon oxide film.

[0006] In view of the foregoing, it is therefore an object of the present invention to provide an element to which an electret condenser has been applied and which has a structure excellent in moisture resistance, such as an ECM (electret condenser microphone). Another object of the present invention is to provide a small-size ECM which does not require a charge supply circuit by producing an ECM composed of an electret having a permanent charge by using a MEMS technology.

MEANS FOR SOLVING THE PROBLEM

[0007] To attain the objects described above, an electret according to the present invention comprises a charged silicon oxide film and an insulating film formed to cover the silicon oxide film.

[0008] A first electret condenser according to the present invention comprises: a first electrode formed with through holes; a second electrode disposed with an air gap interposed between itself and the first electrode; and an electret composed of a charged

silicon oxide film formed on a surface of the second electrode which is opposing the first electrode, wherein an insulating film is formed to cover the silicon oxide film.

[0009] A second electret condenser according to the present invention comprises: a fixed film having a first electrode and formed with first through holes; a second electrode disposed with an air gap interposed between itself and the fixed film; and an electret composed of a charged silicon oxide film formed on a surface of the second electrode which is opposing the fixed film, wherein an insulating film is formed to cover the silicon oxide film.

[0010] A third electric condenser according to the present invention comprises: a semiconductor substrate having a region removed to leave a peripheral portion thereof; and a vibrating film formed on the semiconductor substrate to cover the region, wherein the vibrating film has a multilayer structure composed of an electret, an electrode film, a first insulating film, and a second insulating film and said electret is covered with each of the first insulating film and the second insulating film.

[0011] The electret and electret condenser according to the present invention allows protection of the surfaces of the charged silicon oxide film, i.e., the upper, lower, and side surfaces thereof with the insulating film. Specifically, by covering the silicon oxide film which shows remarkable absorption of atmospheric moisture or the like with the insulating film to prevent the surfaces thereof from being exposed to an ambient atmosphere, it becomes possible to suppress a reduction in the amount of charge in the charged (electretized) silicon oxide film. This allows an improvement in the reliability of the electret.

[0012] In the electret and electret condenser according to the present invention, the insulating film need not directly cover a surface of the charged silicon oxide film (electret), e.g., the upper or lower surface thereof. For example, an electrode may also be interposed

between the lower surface of the silicon oxide film and the insulating film.

[0013] In the electret and electric condenser according to the present invention, the insulating film covering the charged silicon oxide film (electret) preferably has a higher moisture resistance than the silicon oxide film. More specifically the moisture resistance (resistance to charge loss in a given humidity state such as, e.g., a moisture resistance test) of the silicon oxide film covered with the insulating film is higher than that of the silicon oxide film uncovered with the insulating film. As the insulating film having a higher moisture resistance than the silicon oxide film, there can be used, e.g., a silicon nitride film.

EFFECT OF THE INVENTION

[0014] In accordance with the present invention, there can be provided an element to which an electret condenser has been applied and which has an electret structure excellent in moisture resistance, such as an ECM. By producing such an ECM by using a MEMS technology, it becomes possible to provide a small-size ECM which does not require a charge supply circuit. Thus, the present invention renders it possible to implement a high-reliability, small-size, and high-performance microphone. In addition, it also becomes possible to widely supply various practical devices each equipped with the microphone to a society.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIGS. **1(a)** and **1(b)** are structural views of an ECM according to an embodiment of the present invention, of which **1(a)** is a plan view of the ECM and FIG. **1(b)** is a cross-sectional view of the ECM;

FIG. **2** is a circuit block diagram of the ECM according to the embodiment;

FIG. **3** is a cross-sectional view of an electret condenser composing the ECM according to the embodiment;

FIG. **4** is a plan view of the lower electrode of the electret condenser composing

the ECM according to the embodiment and extraction wiring thereof; and

FIG. **5** is a plan view of a silicon nitride film in the fixed film of the electret condenser composing the ECM according to the embodiment.

DESCRIPTION OF NUMERALS

[0016] **18** Microphone Portion

19 SMD

20 FET Portion

21 Printed Board

22 Case for ECM

23 Internal Circuit of ECM

24 Output Terminal

25 Output Terminal

26 External Terminal

27 External Terminal

28 Terminal

29 Terminal

30 Terminal

101 Semiconductor Substrate

102 Silicon Oxide Film

103 Silicon Nitride Film

104 Lower Electrode

105 Silicon Oxide Film

106 Silicon Nitride Film

107 Leak Hole

108 Silicon Oxide Film

109	Air Gap
110	Fixed Film
111	Acoustic Hole
112	Vibrating Film
113	Membrane Region
114	Silicon Nitride Film
115	Extraction Wiring
116	Opening
117	Opening
118	Conductive Film
119	Silicon Nitride Film

BEST MODE FOR CARRYING OUT THE INVENTION

[0017] (Embodiment)

Referring to the drawings, an electret condenser according to an embodiment of the present invention will be described by using the case where it is applied to an ECM as an example.

[0018] A description will be given first to the ECM as an element to which the electret condenser according to the present embodiment has been applied.

[0019] FIGS **1(a)** and **1(b)** are structural views of the ECM according to the present embodiment, of which FIG. **1(a)** is a plan view of the ECM and FIG. **1(b)** is a cross-sectional view of the ECM.

[0020] As shown in FIGS. **1(a)** and **1(b)**, the ECM according to the present embodiment is comprised of: a microphone portion **18;** a SMD (Surface Mounted Device) **19** such as a condenser; and a FET (Field Effect Transistor) portion **20** which are mounted on a printed board **21**. As shown in FIG. **1(b)**, the printed board **21** with the microphone

portion **18**, the SMD **19**, and the FET portion **20** mounted thereon is protected by a case **22**, though the depiction thereof is omitted in FIG. **1(a)**.

[0021] FIG. **2** is a circuit block diagram of the ECM according to the present embodiment.

[0022] As shown in FIG. **2**, the internal circuit **23** of the ECM according to the present embodiment is comprised of: the microphone portion **18** composed of an electret condenser according to the present embodiment, which will be described later; the SMD **19**; and the FET portion **20**. From the output terminals **24** and **25** of the internal circuit **23**, respective signals are outputted to external terminals **26** and **27**. During actual operation, when a signal having a voltage of, e.g., about 2 V is inputted from the terminal **28** which is connected to the external terminal **26** via a resistor, a signal having an AC voltage of, e.g., several tens of microvolts is outputted to the terminal **29** which is connected to the external terminal **26** via a condenser. Each of the external terminal **27** and the terminal **30** connected thereto is connected to the output terminal **25** as the GND terminal in the ECM internal circuit **23**.

[0023] A description will be given herein below to the electret condenser according to the present embodiment. FIG. **3** is a cross-sectional view of the electret condenser according to the present embodiment.

[0024] As shown in FIG. **3**, the electret condenser according to the present embodiment has a parallel-plate condenser structure which uses, as electrodes, a vibrating film **112** formed above a semiconductor substrate **101** having a region (hereinafter referred to as a membrane region **113**) removed to leave the peripheral portion thereof such that the membrane region **113** is covered with the vibrating film **112** and a fixed film **110** disposed with an air gap **109** interposed between itself and the vibrating film **112**. The vibrating film **112** has a lower electrode **104**, while the fixed film **110** has a conductive film (upper

electrode) **118**.

[0025] In the electret condenser according to the present embodiment, when the vibrating film **112** receives a sound pressure from above through a plurality of acoustic holes **111** provided in the fixed film **110** and the air gap **109**, the vibrating film **112** mechanically vibrates upward and downward in response to the sound pressure. When the vibrating film **112** vibrates, the distance (distance between the electrodes) between the vibrating film **112** (i.e., the lower electrode **104**) and the fixed film **110** changes so that the capacitance (C) of the condenser changes accordingly. Since a charge (Q) accumulated in the condenser is constant, the change in the capacitance (C) of the condenser causes a change in the voltage (V) between the lower electrode **104** and the fixed film **110**. The reason for this is that a condition given by the following numerical expression should be physically satisfied.

[0026] $Q = C \cdot V \ldots (1)$

Because the lower electrode **104** is electrically connected to the gate of the FET portion **20** of FIG. **2**, the gate potential of the FET portion **20** changes with the vibration of the vibrating film **112**. The change in the gate potential of the FET portion **20** is outputted as a voltage change to the external output terminal **29**.

[0027] A detailed structure of the electret condenser according to the present embodiment is as follows.

[0028] As shown in FIG. **3**, a silicon oxide film **102** is formed on the semiconductor substrate **101** on which the electret condenser according to the present embodiment is mounted and the membrane region **113** is formed by partially removing the semiconductor substrate **101** and the silicon oxide film **102** such that the respective peripheral portions

thereof remain. Thus, the membrane region **113** is a region formed by partially removing the semiconductor substrate **101** such that the peripheral portion thereof remains to allow the vibrating film **112** to vibrate on receiving a pressure from the outside.

[0029] On the silicon oxide film **102**, the silicon nitride film **103** is formed to cover the membrane region **113**. On the silicon nitride film **103**, the lower electrode **104** and extraction wiring **115**, each composed of the same conductive film, are formed. The lower electrode **104** is formed on the silicon nitride film **103** covering the membrane region **113** and a vicinity region thereof (a part of an external region of the membrane region **113**). The extraction wiring **115** is formed on the portion of the silicon nitride film **103** which is located outside the membrane region **113** to be connected to the lower electrode **104**.

[0030] Over each of the silicon nitride film **103**, the lower electrode **104**, and the extraction wiring **115**, a silicon oxide film **105** and a silicon nitride film **106** are formed successively. The vibrating film **112** is constituted herein by the lower electrode **104** composed of the conductive film and the respective portions of the silicon nitride film **103**, the silicon oxide film **105**, and the silicon nitride film **106** which are located in the membrane region **113**. The vibrating film **112** is also formed with a plurality of leak holes **107** each connecting to the air gap **109**. Each of the silicon nitride films **103** and **106** is formed to cover the entire surfaces of the lower electrode **104** and the silicon oxide film **105** including the inner wall surfaces of the leak holes **107**. The silicon oxide film **105** is an electret film having a charge accumulated therein. Specifically, the charge is injected in the silicon oxide film **105** by exposing the silicon oxide film **105** during a corona discharge or plasma discharge so that the silicon oxide film **105** electretized thereby is formed successfully. At this time, the silicon oxide film **105** may be either exposed or covered with the silicon nitride films **103** and **106** during the corona discharge or plasma discharge.

[0031] As shown in FIG. 3, the fixed film **110** composed of the conductive film **118**

covered with a lower-layer silicon nitride film **114** and an upper-layer silicon nitride film **119** is further formed above the vibrating film **112**, i.e., above the silicon nitride film **106**. The air gap **109** is formed between the vibrating film **112** and the fixed film **110** in the membrane region **113** and the vicinity region thereof (a part of the external region of the membrane region **113**), while a silicon oxide film **108** is formed between the silicon nitride film **106** or the silicon oxide film **102** and the fixed film **110** in the other region. In other words, the air gap **109** is formed over a region including at least the entire membrane region **113**, while the fixed film **110** is supported above the vibrating film **112** by the silicon oxide film **108**.

[0032] The fixed film **110** located above the air gap **109** is formed with a plurality of acoustic holes **111** each connecting to the air gap **109**. An opening **116** is provided in the fixed film **110** including the silicon nitride film **114** and in the silicon oxide film **108** to partially expose the extraction wiring **115**. The lower electrode **104** is electrically connected to the gate of the FET portion **20** shown in FIG. **2** via the extraction wiring **115**. In addition, an opening **117** is provided in the silicon nitride film **119** composing the fixed film **110** and the conductive film **118** composing the fixed film **110** is exposed therein such that the conductive film **118** is electrically connected thereby to the GND terminal **25** of FIG. **2**.

[0033] FIG. **4** is a plan view of the lower electrode **104** of the electret condenser according to the present embodiment and the extraction wiring **115** thereof. As stated previously, each of the lower electrode **104** and the extraction wiring **115** is composed of the same conductive film. As shown in FIG. **4**, the lower electrode **104** is formed inside the membrane region **113** and the plurality of leak holes **107** are formed in the peripheral portion of the lower electrode **104**. The extraction wiring **115** is formed to electrically connect the lower electrode **104** to the outside.

[0034] A description will be given herein below to the reason that the lower electrode **104** is formed inside the membrane region **113**. The capacitance of the condenser in the ECM is determined by a capacitance component which varies with the vibration of the vibrating film and by a capacitance component which does not vary with the vibration of the vibrating film. When a parasitic capacitance increases, the capacitance component which does not vary with the vibration of the vibrating film increases disadvantageously so that the performance of the ECM is greatly influenced thereby. To prevent this, the present embodiment has provided the lower electrode **104** of the electric condenser inside the membrane region **113**. Since the arrangement eliminates the overlapping region between the lower electrode **104** and the semiconductor substrate **101**, it is possible to eliminate a large-area MOS (metal oxide semiconductor) capacitance composed of the lower electrode **104**, the silicon oxide film **102**, and the semiconductor substrate **101**. More specifically, the parasitic capacitance can be limited only to a small-area MOS capacitance composed of the extraction wiring **115**, the silicon oxide film **102**, and the semiconductor substrate **101**. As a result, an increase in the capacitance component (parasitic capacitance) which does not vary in the condenser can be prevented and therefore a small-size and high-performance condenser can be implemented.

[0035] Of the components of the vibrating film **112** according to the present embodiment, i.e., of the silicon nitride film **103**, the lower electrode **104** composed of the conductive film, the silicon oxide film **105**, and the silicon nitride film **106**, the silicon nitride film **103**, the silicon oxide film **105**, and the silicon nitride film **106** each formed to cover the membrane region **113** are formed to overlap the semiconductor substrate **101**. In other words, the respective end portions of the silicon nitride film **103**, the silicon oxide film **105**, and the silicon nitride film **106** are located above the semiconductor substrate **101**. On the other hand, the lower electrode **104** of the vibrating film **112**, which is

composed of the conductive film, is formed inside the membrane region **113** not to overlap the semiconductor substrate **101**. In other words, the end portion of the lower electrode **104** is located inside the membrane region **113**. The arrangement allows the resonant frequency characteristic of the vibrating film **112** to be controlled by adjusting the film thickness of each of the silicon nitride film **103**, the silicon oxide film **105**, and the silicon nitride film **106**. Thus, by allowing easy control of the capacitance component which varies under a pressure from the outside of the condenser, a small-size and high-sensitivity electret condenser can be implemented.

[0036] A description will be given herein below to the reason that the silicon nitride films **103** and **106** are formed to cover the lower electrode **104** and the silicon oxide film **105**. When the electret composed of the silicon oxide film comes in contact with a liquid, the charge in the electret is significantly reduced. To suppress the reduction in the charge of the electret, the present embodiment has covered at least the surfaces (upper, lower, and side surfaces) of the silicon oxide film **105** serving as the electret with the silicon nitride films **103** and **106**. More specifically, the inner wall surfaces of the leak holes **107** are also covered completely with the silicon nitride film **106** such that the silicon oxide film (electret) **105** is not exposed in each of the leak holes **107** formed in the vibrating film **112**. As a result, it becomes possible to implement an electret condenser having an electret which is excellent in moisture resistance and heat resistance.

[0037] FIG. **5** is a plan view of the silicon nitride film **114** composing the fixed film **110** of the electret condenser according to the present embodiment. As described above, the plurality of acoustic holes **111** are formed in the fixed film **110** formed above the semiconductor substrate **101** including the membrane region **113**. Each of the acoustic holes **111** is located in the membrane region **113** and the vicinity region thereof (a part of the external region of the membrane region **113**).

[0038] A description will be given herein below to the operation of the electret condenser according to the present embodiment. In the electret condenser according to the present embodiment shown in FIG. 3, when the vibrating film **112** receives a sound pressure from above through the acoustic holes **111** and the air gap **109**, it mechanically vibrates upward and downward in response to the sound pressure. The electret condenser according to the present embodiment has a parallel-plate condenser structure using, as the electrodes, the lower electrode **104** composing the vibrating film **112** and the conductor film **118** composing the fixed film **110**. Accordingly, when the vibrating film **112** vibrates, the distance between the lower electrode **104** and the conductive film **118** as the electrodes changes to change the capacitance (C) of the condenser. Since the charge (Q) accumulated in the condenser is constant, the change in the capacitance (C) of the condenser causes a change in the voltage (V) between the lower electrode **104** and the fixed film **110** (conductive film **118**). The reason for this is that the condition given by the following numerical expression (1) should be physically satisfied.

[0039] $Q = C \cdot V$ ... (1)

In addition, when the voltage (V) between the lower electrode **104** and the fixed film **110** (conductive film **118**) changes, the gate potential of the FET portion **20** also changes because the lower electrode **104** is electrically connected to the gate of the FET portion **20** of FIG. **2**. Thus, the vibration of the vibrating film **112** changes the gate potential of the FET portion **20** so that the change in the gate potential of the FET portion **20** is outputted as a voltage change to the external output terminal **29** of FIG. **2**.

[0040] As described above, the present embodiment allows protection of the charged silicon oxide film **105** with the silicon nitride films **103** and **106**. Specifically, by covering

the surfaces of the silicon oxide film **105** made of a material showing remarkable absorption of atmospheric moisture or the like with the silicon nitride films **103** and **106** to prevent the silicon oxide film **105** from being exposed to an ambient atmosphere, it becomes possible to suppress a reduction in the amount of charge in the silicon oxide film **105.** This allows an improvement in the reliability of the electret. As a result, an electret condenser having an electret structure which is excellent in moisture resistance, such as an ECM, can be provided. By producing such an ECM by using a MEMS technology, a small-size ECM which does not require a charge supply circuit can be provided.

[0041] Thus, the present embodiment makes it possible to implement a high-reliability, small-size, and high-performance microphone and also widely supply various practical devices each equipped with the microphone to a society.

[0042] Although the present embodiment has covered the lower surface of the charged silicon oxide film **105** with the silicon nitride film **103** with the lower electrode **104** interposed therebetween, the lower surface of the silicon oxide film **105** may also be covered directly with the silicon nitride film.

[0043] Although the present embodiment has covered the surface of the charged silicon oxide film **105** with the silicon nitride film, the surface of the charged silicon oxide film **105** may also be covered with an insulating film of another type having a higher moisture resistance than the silicon oxide film instead of the silicon nitride film.

[0044] Alternatively, the present embodiment may also use silicon or polysilicon doped with an impurity, gold, a refractory metal, aluminum, an aluminum-containing alloy, or the like as a conductor material composing the lower electrode **104**.

[0045] Alternatively, the present embodiment may also use silicon or polysilicon doped with an impurity, gold, a refractory metal, aluminum, an aluminum-containing alloy, or the like as the material of the conductive film **118** composing the fixed film **110**.

[0046] In the present embodiment, a substrate made of an insulating material may also be used instead of the semiconductor substrate **101**.

INDUSTRICAL APPLICABILITY

[0047] The present invention relates to an electret condenser having a vibrating electrode and a fixed electrode. When applied to an ECM formed by using a MEMS technology or the like, the present invention can particularly improve the performance and reliability of the ECM and is therefore extremely useful.